Driver Behavior at Highway-Rail Grade Crossing Using NDS and Driving Simulators

2017 Grade Crossing Research Needs Workshop
St. Louis, Missouri
Outline

• Project 1: In-Vehicle Auditory Alerts (IVAA) – Summary
  – Warning types
  – What type of warning works best?
  – Results

• Project 2: Driver Behavior at Highway-Rail Grade Crossings Using NDS Data and Driving Simulators
  – Description of Naturalistic Driver Study (NDS) database
  – Driver compliance behavior
  – Crossing selections
  – Project progress – NDS analysis
  – Project progress – Simulator research
  – Next steps
In-Vehicle Alerts; How to Warn Drivers?

**Stimuli**

- **31 novel auditory cues**
  - 9 Earcons (Beeps)
    - Varied in pitch, pulse rate, wave shape, etc.
  - 6 Auditory Icons (train sounds)
    - Train horns, “track” sounds, warning bells, etc.
  - 16 Verbal messages
    - 2 Genders (M, F)
    - 2 Voice types (Human, TTS)
    - 4 words (Alert, Caution, Danger, Warning)

**Subjective Measurements**

- **7 psychological dimensions**
  - Likert scale 1-7
  - Overall Appropriateness
  - Urgency
  - Meaning
  - Discriminability
  - Annoyance
  - Startle effect
  - Natural-In-Car

Baldwin & Lewis, 2014
Analysis of Alternatives

- Principal Component Analysis suggested two main factors (95% of variance explained across all 7 dimensions)
  - “Utility” – meaning & natural & urgency
  - “Impulsivity” – annoying & startle
- Verbal messages more utility, but Earcons more impulsive
- Auditory Icons somewhere in the middle
- Technique also helped identify the acoustic features relevant for embedding urgency into Earcons.

### Perceived Urgency

<table>
<thead>
<tr>
<th>Perceived Urgency</th>
<th>Wave Shape</th>
<th>Number of beeps</th>
<th>Cycle rate</th>
<th>Pitch</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>Saw</td>
<td>Multiple</td>
<td>&gt; 3 per second</td>
<td>&gt; 2000 hz</td>
</tr>
<tr>
<td>Low</td>
<td>Sine</td>
<td>Single</td>
<td>&lt; 2 per second</td>
<td>&lt; 1500 hz</td>
</tr>
</tbody>
</table>
Evaluation of System Performance

- **Auditory warning of approaching crossing**
  - Requires GPS + crossing location database
  - No vehicle-train communication necessary (no approaching train warnings)
- **Increase saliency, especially at passive crossings**
- **Remind drivers to and how to comply**

**Compliance Coding Scheme**
- +1 for each direction looked (max 2)
- +1 for coasting (releasing accelerator pedal)
- +1 for slowing down (press on brake pedal)
- -1 for not coming to a complete stop at a STOP sign

“ding ding, Railroad Crossing ahead, look left and right”
Scenario Design

Two “tracks” per driver
- (~22 minutes each)
- One track with, one without IVAAAs

One “track” = 3 laps around scenario
- Each lap contains 4 crossings, 1 of each sign type
- Total of 24 observations per participant

Train present at 23rd crossing (gate)
Compliance Results

• Increased compliance through auditory alerts
  • \( B_1 = B_2 = A_2 > A_1 \)

- A1, Start with no IVAA
- A2, Add IVAA
- B1, Start with IVAA
- B2, Finish with no IVAA
Gated Crossings Show Greatest Improvement

*Statistically Significant
NDS/Simulator Project
Description and Goals

• Schedule: September, 2016 – August, 2018
• Integrate “Naturalistic Driver Study (NDS)” and “Driver Simulator” research to better understand driver behavior at highway-rail grade crossings
• 94 % of all accidents are caused by “human behavior”
  – Even risky behavior rarely leads to an accident
• The goal is to understand the driver behavior
  – CURRENT: Evaluate effectiveness of current traffic warning/control devices
  – FUTURE: Suggest improvements for future system improvements
SHRP2-Naturalistic Driving Study

- Naturalistic driving data
  - Data are live recorded in-vehicle
  - Behavior expected to be very similar to the natural environment
  - Expensive and difficult to set up

- SHRP2-NDS
  - Data collected between 2011 and 2013
  - 3,500 Vehicles in 6 Regions: FL, IN, NY, NC, PA, WA
  - More than five million trips and over 1,000 crossings involved
  - Data used to analyze driver behavior at grade crossings, *primarily in non-accident situations*
Crossing selection from the NDS

<table>
<thead>
<tr>
<th>STATE</th>
<th>CROSSINGS IN NDS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Florida</td>
<td>295</td>
</tr>
<tr>
<td>Indiana</td>
<td>104</td>
</tr>
<tr>
<td>New York</td>
<td>181</td>
</tr>
<tr>
<td>North Carolina</td>
<td>168</td>
</tr>
<tr>
<td>Pennsylvania</td>
<td>61</td>
</tr>
<tr>
<td>Washington</td>
<td>208</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>1017</strong></td>
</tr>
</tbody>
</table>

- The type of traffic control devices verified/corrected with Google Maps
- Three primary main states of interest: Florida, Indiana, New York (to allow contrast in environment conditions)
- GOAL: Statistically significant number of crossings in each category
  - Most of the crossings in the study were active with lights and gates
Compliance Score

• Compliance based on:
  – Scanning behavior (2 points)
  – Speed adjustment/braking (1 point)

• What’s needed to see the train?
  – 8 degree radius threshold around origin for looking at road – (Ahlstrom, Victor, Wege, Steinmetz, 2012)

• Timing of actions vs. compliance
  – Timing of head rotation
  – Timing of speed reduction/braking (if applicable)
Compliance Scoring – Example 1

No significant speed decrease (0)

No Rotation outside 8 degrees

Pitch within 8 degrees

No scanning behavior (0)

<table>
<thead>
<tr>
<th>Compliance Score</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed Decrease</td>
<td>0</td>
</tr>
<tr>
<td>Scanning Behavior</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>0</td>
</tr>
</tbody>
</table>
Compliance Scoring – Example 2

<table>
<thead>
<tr>
<th>Compliance Score</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed Decrease</td>
<td>+1</td>
</tr>
<tr>
<td>Scanning Behavior</td>
<td>+2</td>
</tr>
<tr>
<td>Total</td>
<td>+3</td>
</tr>
</tbody>
</table>
Evaluation of compliance score
Evaluation of compliance score

• Compliance scores distribution analysis
• Over 5,000 traversals have been processed to date
• Comparison and correlation analysis based on average compliance scores per cluster
• Clusters are based on:
  – Traffic control devices (passive, active w/ lights, active w/ lights & gates)
  – Angle of the crossing
  – Total trains per day
  – Highway maximum speed
Scores - Crossing Type

- 2 sample t-test used to verify statistical difference between categories
## Where do Drivers Fall Short?

<table>
<thead>
<tr>
<th>TYPES OF CROSSINGS</th>
<th>SCANNING SCORE (%)</th>
<th>SPEED REDUCTION SCORE (%)</th>
<th>OVERALL COMPLIANCE (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passive</td>
<td>66%</td>
<td>71%</td>
<td>68%</td>
</tr>
<tr>
<td>Active with Lights only</td>
<td>57%</td>
<td>63%</td>
<td>59%</td>
</tr>
<tr>
<td>Active with Lights and Gates</td>
<td>45%</td>
<td>44%</td>
<td>46%</td>
</tr>
</tbody>
</table>

- The scanning vs. speed reduction behavior offers similar trending with all main TCDs
- Standard deviations are large
Compliance Score Vs Highway Speed

- Investigate compliance score variation on trends found to “increase risk of accidents”
- Percentage of gated crossings increases as highway speed increases
- More data are needed in some of the clusters
Phase II - Driving Simulator Research

• GOAL: Investigate “simulated” behavior vs. “NDS behavior”
• Will focus initially on existing crossings that are easy to model in simulator using as much of the existing tiles as possible
• Inclusion of crossings based on tiles from past research
  – All are close to right angle crossings (90 degrees)
  – There are four main configuration types:

- **Fully blocked view and no intersection nearby**
- **Partially blocked view & no intersection nearby**
- **Clear view and no intersection nearby**
- **Clear view with intersection nearby**
Conclusions (to Date)

• In-Vehicle Auditory Alerts (IVAAAs) offer an intriguing new way to alert drivers on approach to crossings
  – Simulator results show clear improvement in driver compliance
• SHRP2-NDS database offers unique opportunity for large scale investigation of drivers behavior at crossings
  – Drivers are more compliant at passive crossings than active
  – Initial results with other parameters are interesting, but not conclusive
Future Research

• Compliance score improvements
• Trends and correlation analysis with larger data samples
• Driver reaction to rough crossings
• Combined effect of different parameters
• Demographics (age and gender)
• Compare simulator results with NDS
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Thank You!